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Yoshinori Ishida
Panasonic Corporation, Japan, ishida.yoshinori@jp.panasonic.com

Naoya Nakashima
Meijo University, Japan, 120434047@ccalumni.meijo-u.ac.jp

Hatsuhiko Usami
Meijo University, Japan, usami@ccalumni.meijo-u.ac.jp

Friction Properties of Journal Bearing having Bell-Mouth Geometry

Yoshinori ISHIDA[1]*, Hatsuhiko USAMI[2], Naoya NAKASHIMA[2]

[1]Panasonic Corporation, Appliances Company, Kusatsu, Shiga, Japan
Phone: +81-50-3688-7414, fax: +81-77-561-3201 E-mail: ishida.yoshinori@jp.panasonic.com

[2]Meijo University, Nagoya, Aichi, Japan
Tel: +81-52-838-2155, fax: +81-52-832-1235, E-mail: usami@ccalumni.meijo-u.ac.jp

*Corresponding Author

Abstract

The present study describes an applicability of a bell-mouth geometry to improve tribological properties of the journal bearing of reciprocating compressors used for refrigerators. To fabricate the bell-mouth geometry to the journal bearing, a deep rolling process was applied to the edge surface. The resulting geometry of the bearing edge consisted of a micro-scale gradient of 1/1000 and a length of 4-6 mm. The tribological properties were evaluated with a specially-developed testing apparatus at a constant sliding speed under lubricated conditions. The applied load increased incrementally to evaluate tribological behavior including seizure occurrence. Actual components for the journal bearing were used as the specimen. Results showed that a significant improvement of tribological properties by the application of bell-mouth geometry. Contact stress analysis and estimating lubricating condition were conducted to estimate the tribological properties. Consequently, it is concluded that the application of the bell-mouth geometry is effective means to for improving the tribological properties of journal bearing for reciprocating compressors.

1. Introduction

It is well recognized that an efficiency improvement of refrigerators is effective and important factors to prevent global warming. As Itou *et al.* (2005) has pointed out, reduction of friction resistance of the journal bearing of the compressor is the key technology to improve the efficiency of refrigerators. The journal bearing system of the compressor consists of the crank shaft and bearing and is support variable centrifugal force caused by reciprocal movement of piston. Lots of modification techniques have been attempted to improve tribological properties. However, applicable method was actually restricted due to the production cost.

It is found that an application of a barrel shape to the rolling element is effective means to decrease in the friction loss of the roller bearing, since the contact area expands and the local contact stress decreases. As results, the friction loss and the wear loss related to the stress concentration may decrease by Fujiwara *et al.* (2006). Similar contact surface configuration to the barreled shape roller bearing is possible to obtain the contact surface consisting of a bell-mouthed shape bearing and straight shaft.

The present study describes applicability of the bell-mouth geometry to the edge surface of the journal bearing for reciprocating compressor. A modified deep rolling process, frequently used as surface finishing process for soft metals, is applied to the bell-mouth geometry. The tribological properties are evaluated using actual compressor components. Effects of bell-mouthed shape fabrication on the tribological properties including seizure is discussed.

2. Structure and issues of reciprocating compressor

A schematic of a conventional reciprocating compressor for refrigerators was shown in Fig. 1. The crank shaft is supported like a cantilever in the main bearing section. As Matsui *et al.* (2010) have mentioned, the load in radial direction acting as the contact load in the bearing applied to the crank shaft during the refrigerant suction and compression process varied more than 10 times, since the crank shaft rotated accompanying with piston and connecting rod. As results, the contact condition became much severe and solid contact frequently occurred despite that sufficient supplement of lubricants. Recently, the usage of lower viscosity oils are strongly demanded to reduce friction resistance in hydrodynamic lubrication regime. Therefore, the operating condition of the journal bearing became much severe, and an application of an effective means to decrease in friction and wear are anticipated.

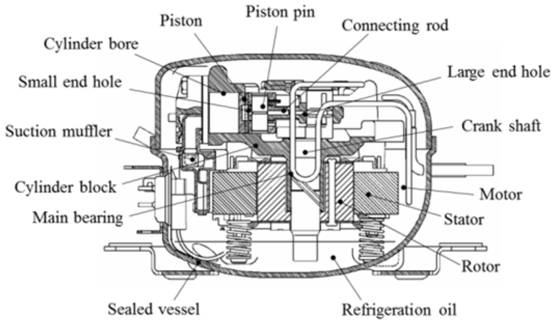


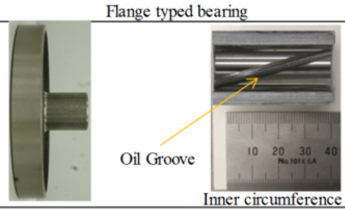
Figure 1: Schematic of reciprocating compressor

3. Experiment

3.1 Specimens

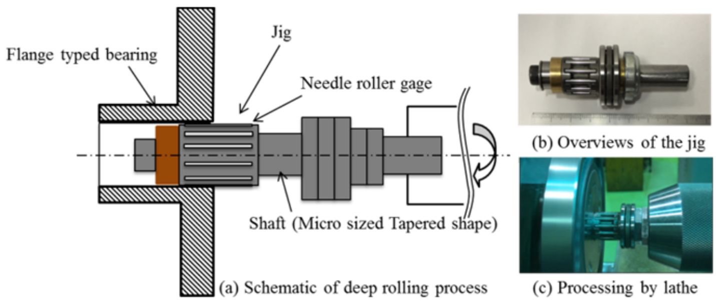
Actual components of the compressor, the flange typed bearing and the crank shaft were used as specimens. An overview and specification of the specimens were shown in Table 1. The material of spceimen was gray cast iron and the testing surface was finished with polishing. In addition, manganses phospahte was coated on the shaft surface. An spiral oil groove was formed on the bearing surface.

Table 1: Actual test specimens

Name	Shaft	Flange typed bearing
Test specimen		 Oil Groove Inner circumference
Material	FC250	FC250
Size	φ15.995(a.v.g), Length : 100mm	φ16.011(a.v.g), Length : 40mm
Notices	Surface treatment : Manganese phosphate treatment	Oil groove size : Depth 0.8mm, Width 1.0mm

3.2 Process for bell-mouthed shape application

Bell-mouthed shape was formed to the edge surface of the bearing using a deep rolling process. A schematic of deep rolling process, overviews of the jig and the process were shown in Fig. 2. The jig consisted of micro sized tapered shaft and the needle roller gage. Needle rollers installed to the gage was aligned along to the slope. As shown in the schematic, the jig was pressed into the journal bearing then plastic deformation near the inner surface of the journal bearing resulted in the bell-mouthed shape at the edge surface.



(a) Schematic of deep rolling process (b) Overviews of the jig (c) Processing by lathe

Figure 2: Deep rolling process

The bell-mouth geometry was occasionally applied to the upper (flange side) and/or the lower edge and the bearing was nominated as UEB for upper edge, LEB for lower edge and BEB for both edges bell-mouthed. None processed, bearing without bell-mouthed was also conducted as NB. A surface profile of the bearing was shown in Fig. 3. Micro sized inclination of the slope of 4-6 mm of the length and 4-6 μm of the depth was applied to the bell-mouthed process. In addition, the bell-mouthed process resulted in the decrease of the surface roughness.

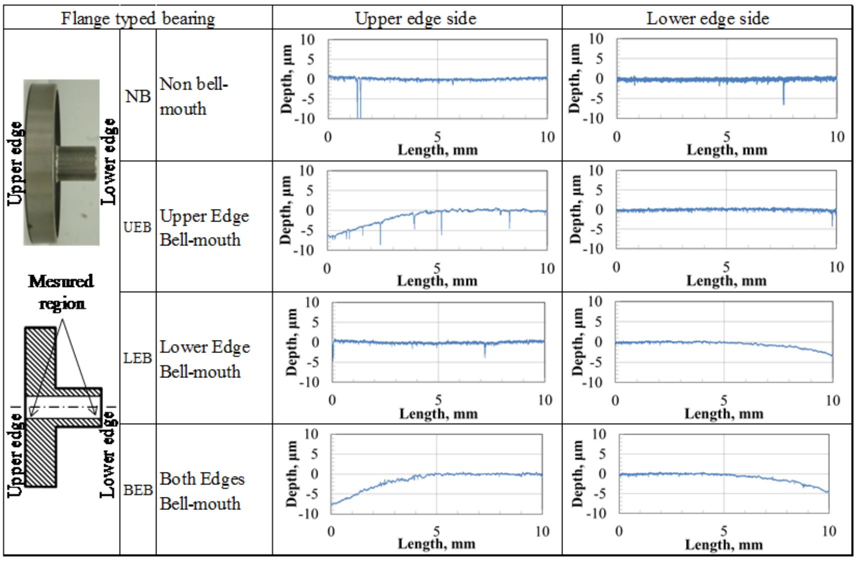
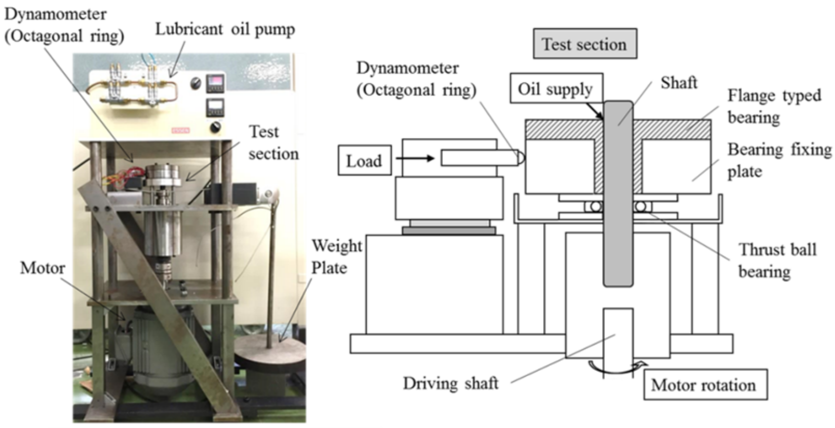


Figure 3: Primary profile of bearing surfaces after deep rolling

3.3 Apparatus and test condition

A testing apparatus was developed to evaluate an actual operating condition of reciprocating compressor subjected to the partial contact resulting in the eccentric motion of the crank shaft. A schematic of the testing apparatus was shown in Fig. 4(a) and 4(b). The shaft specimen was connected to the drive shaft using collet chuck. The rotational accuracy of the shaft was adjusted less than 2μm in a radial run out. The Flange typed bearing fixed to the plate was mounted on a thrust ball bearing inserting the shaft. The normal load was applied by pulling the plate with dead weight. An octagonal shape dynamo meter was installed between loading point and the plate. The journal is possible to move to upper vertical direction along the shaft deflection. Therefore, the mismatch of the deflection of the shaft tilt of the bearing resulted in the partial contact. The testing conditions were listed in Table 2. Two testing conditions, 1 and 2 were settled for the evaluation of seizure and steady state friction properties, respectively. Lubricant oil was supplied to oil groove from the upper end of the journal bearing at a constant flow rate of 15ml/20sec.



(a) Overviews of testing apparatus (b) Schematic

Figure 4: Schematic of testing apparatus and test conditions

Table 2: Testing condition

	Testing condition 1	Testing condition 2
Load	300-500-700-900N	100-300-500-700N
Rotational speed	1200rpm	600rpm
Velocity	1.0m/s	0.5m/s
Step distance	1800m	900m
Oil	SP oil (22mm2/s @40℃)	
Lubricant oil amount	15mm3/20sec	
Bearing clearance	16μm	

4. Test results

4.1 Frictional coefficient

The friction coefficient calculated from the applied load and the friction force was shown in Fig. 5. A rapid increase in the friction coefficient was found in results on the testing condition 1 except of that of BEB, both edges bell-mouthed bearing. Seizure was determined from the rapid increase in the friction coefficient. The friction coefficient of the non bell-mouthed (NB) bearing was high and slightly increased with the increase in the sliding distance. Similar behavior of the friction coefficient such as the slightly and the rapid increase was found of the UEB, upper edge bell-mouthed and LEB, lower edge bell-mouthed bearings. However, the sliding distance up to seizure increased and the friction coefficient at the beginning of the experiment was lower than that of NB bearing. The friction coefficient of BEB bearing was low and stable from the beginning of the experiment and decreased with the increase in the applied load up to a load of 900 N without seizure. Therefore, it was found that the application of the bell-mouth geometry to the edge region of the journal bearing was effective to improve an anti-seizure property.

In the testing condition 2, the effect of the bell-mouth geometry on the friction coefficient was relatively small at an applied load of 100 N but was larger at a load of 700 N. The friction coefficient of BEB, UEB and LEB bearings was approximately 0.01and was 1/3 compared with that of NB bearing. From above mentioned, the effectiveness of the bell-mouth geometry to the edge surface on the friction properties including anti-seizure properties was confirmed.

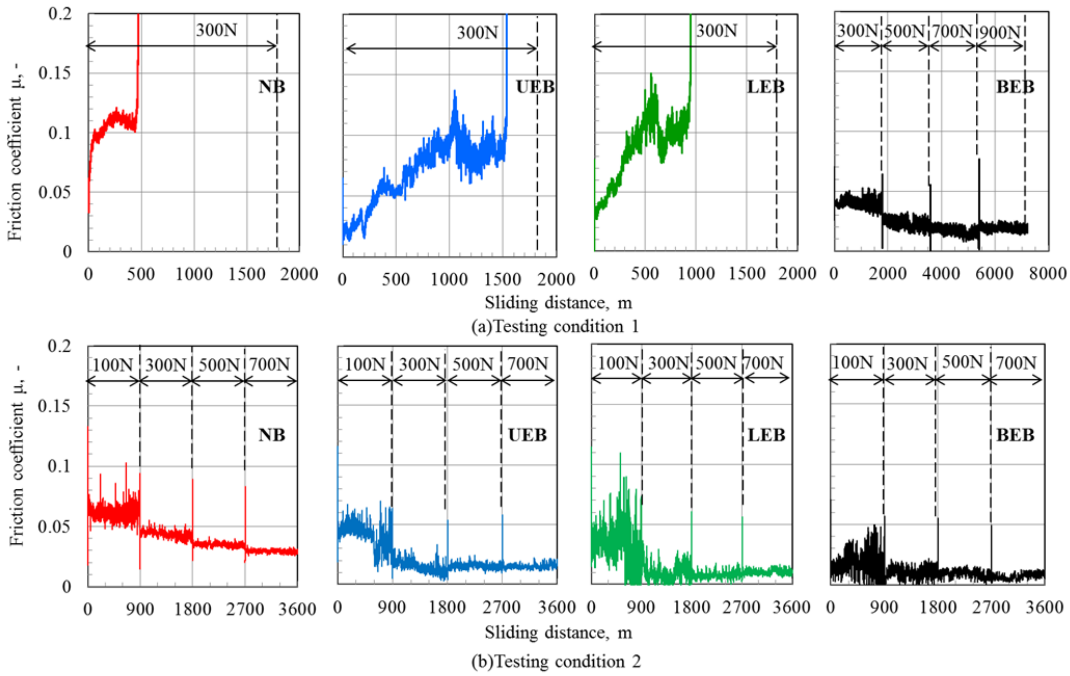


Figure 5: Friction Coefficient as a function of sliding distance

4.2 Wear scar

An optical micro scope image and the surface profile focused near the damage region of the shaft and bearing surface was shown in Fig. 6 for the testing condition 1, and Fig. 7 for testing condition 2. A wide and deep groove accompanied with pile up was formed on the lower surface except in the case of BEB bearing (Fig. 6). The position of the groove was corresponded between the shaft and the bearing. The groove size on the shaft surface mated with BEB bearing was narrow and shallow. In particular, no grooves were found on the BEB bearing surface.
In results in the testing condition 2, the groove depth and width was small however, the depth on the shaft surface mated with NB bearing was larger. Considering the friction behavior, no seizure occurred on BEB surface, it was estimated that seizure resulted in the wide and deep groove in the result of testing condition 1.
From above mentioned, it was found that adopting the bell-mouth geometry in at least one of the edges of the bearing, wear scar of the sliding surface improved considerably. In addition, deep rolling could be applied to bell-mouthed shape processing at the edges of gray cast iron bearings with poor ductility.

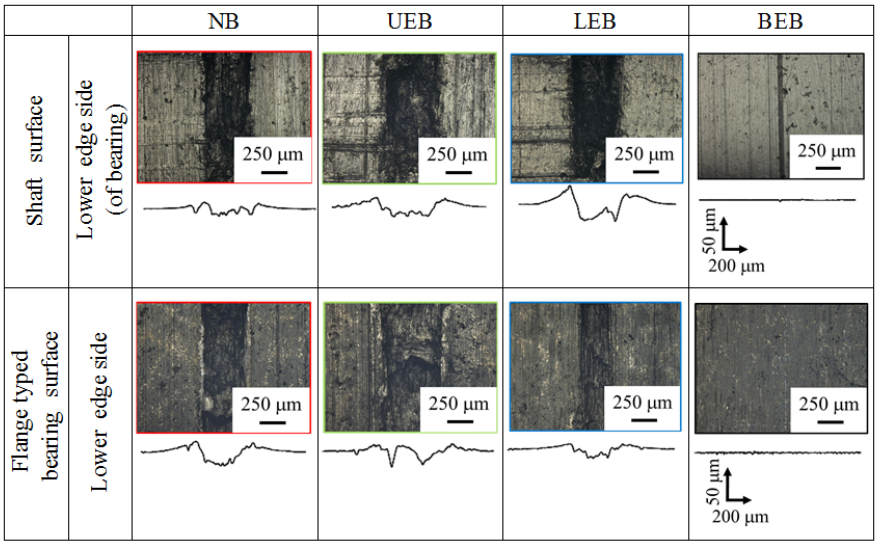


Figure 6: Optical micrograph and surface profile of shaft and bearing surfaces (Test cond. 1)

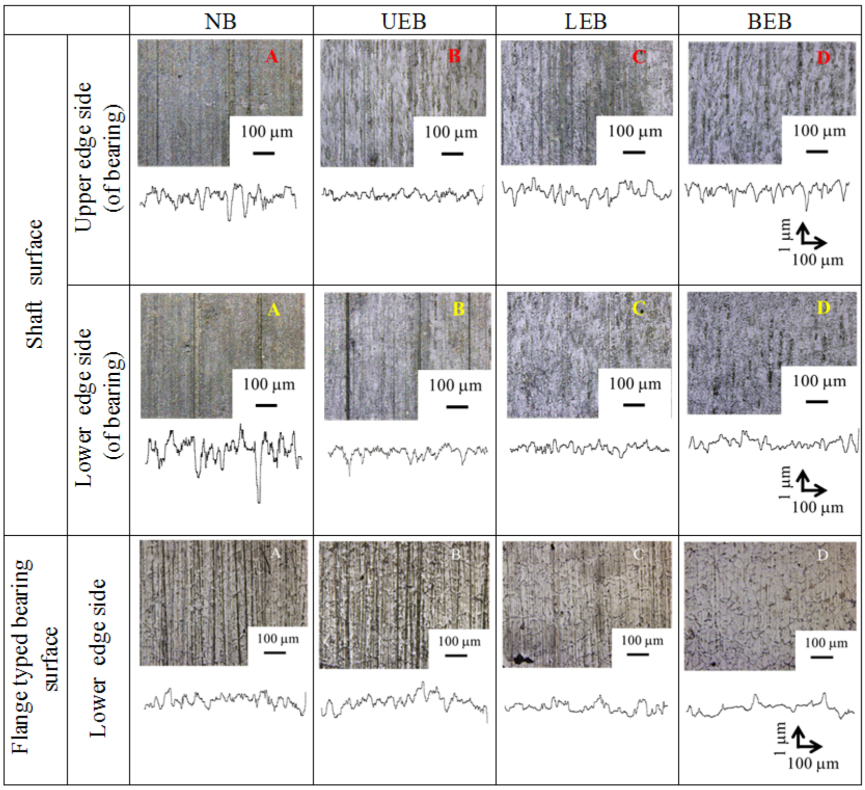


Figure 7: Optical micrograph and surface profile of shaft and bearing surfaces (Test cond. 2)

5. Discussion

5.1 Effect of bell-mouth geometry on contact condition

Since the shaft specimen was fixed to the drive shaft at one end as a cantilever and bended in loading, the mismatch of the surface profile at the interface resulted in the partial contact between the shaft and the bearing. If the deflection was larger than the clearance at the interface, the bearing became incline. To evaluate the contact condition, the inclination of the bearing in loading was measured. A schematic of the incline measurement of the bearing and the results was shown in Fig. 8. NB and BEB bearing was used for the measurement. The inclination of the NB bearing increased linearly with the increase in the contact load. This suggested that the contact position was edge of the bearing and was fixed.

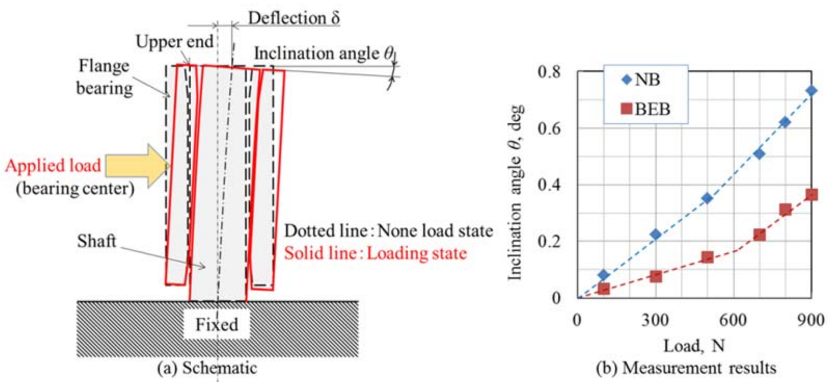


Figure 8: Inclination angle θ as function of load condition

In contrast, the increase of the inclination angle of BEB bearing was low less than 700 N of applied loads and constant. The slope of the inclined angle became larger at more than 700 N. The clearance near the edge was larger than that of inner region of BEB bearing and the inner diameter of the NB bearing was constant against bearing length. Therefore, a capability of the deflection was larger and the contact region was possible to shift toward inside in BEB bearing. This suggested that the contact area expanded to apply bell-mouth geometry.

Considering the effect of the edge surface profile of journal bearing on tribological properties, the bell-mouth geometry resulted in the decrease and stabilize of friction coefficient and the increase of the anti-seizure properties. A deep and wide groove accompanied with pile up was formed near the edge region both on the shaft and on the bearing surface. In contrast, several shallow grooves were found on the surface without seizure. From the results of the relation between the deflection of the shaft and the inclination angle of the bearing, not only the increase in the clearance but also the shift of the contact region on bell-mouth geometry was suggested. As Nakashima *et al.* (2017) have mentioned, a finite elemental analysis showed that a contact stress distribution of bell-mouthed bearing expanded and spread along the bearing length. Therefore, it was concluded that the application of bell-mouth geometry was effective means to improve the friction properties including seizure of the journal bearing.

5.2 Application to compressor

To ascertain the effect of the bell-mouth application on the performance and reliability of reciprocating compressor, it was evaluated using the actual compressor system. NB and BEB bearings were used. Figure 9 (a) shows the results of compression performance. BEB bearing improved COP (coefficient of performance) by about 1% compared to NB bearing. FIG. 9 (b) shows the surface profile of the shaft after the reliability operation test. Wear occurred on the shaft surface mated with the edge of the NB bearing, but wear of the shaft was remarkably suppressed in the BEB bearing.

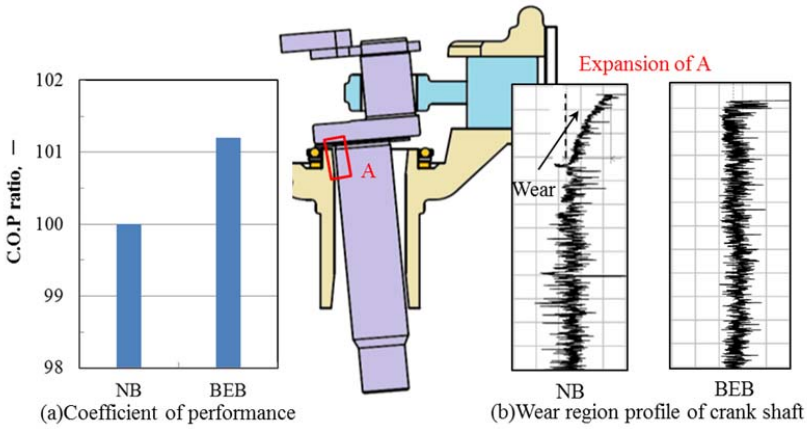


Figure 9: Result of compressor test

From the above, it was found that the compression performance was improved by mounting the bell-mouthed shape at the edges of journal bearing of the reciprocating compressor, so it was possible to reduce the power consumption of the refrigerator. In addition, it was considered that deep rolling process was effective in fabricating bell-mouthed shape and it could be applied to mass production.

6. Conclusion

Friction properties of journal bearing having bell-mouth geometry consisted of micro sized slope fabricated with a deep rolling process was evaluated with a developed apparatus using actual components of reciprocating compressor. Followings are summary of obtained results.

(1) An application of a micro sized bell-mouth geometry to the edge region of the inner surface of the bearing is effective means to reduce and to stabilize the friction resistance.
(2) A deep rolling process is available to fabricate the bell-mouth geometry for cast iron for compressor components.
(3) The effect of the bell-mouth geometry on the compressor performance is confirmed on the actual compressor system.

References

Ito, Hattori and Honma: Lubrication Analysis of a Journal Bearing for Recipro Compressors (Effects of Oil Groove), The Proceedings of the JSME Annual Meeting, Vol.5-1, (2005) 143.

Fujiwara and Kawase: Logarithmic Profile of Rollers in Roller Bearing and Optimization of the Profile, Transactions of the Japan society of mechanical engineers. C, Vol.72, (2006) 3022.

Matsui, Kitsunai and Inagaki: Analytical Technology for Mixed Lubrication in Journal and Thrust Bearings of Reciprocating Compressor, Panasonic Technical Journal, Vol.55, No4, (2010) 21.

Nakashima, Ishida and Usami: Effect of edge geometry on friction properties of journal bearing of refrigerator, The Tribology Conference 2017 Fall, Proceedings.